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Underclothing and its Physiological Effects in a Hot-Dry Environment

by

Fred R. Winsmann, Roger G. Soule, and Ralph F. Goldman

When underclothing of any type is worn, data collected using our static, copper manikin clearly indicate a slightly increased insulation and decreased evaporative transfer. In order to assess air movement in the dynamic state ("pumping"), the present study involved 8 men (21.2 yr., 175.2 cm and 69.1 kg) to evaluate ~~four~~ 4 underclothing systems worn under a desert uniform: (1) no underwear; (2) std boxer shorts and t-shirt; (3) fish net "Brynje"; and (4) ladder net "Brynje". The physiological trial was designed using the copper man data to select an environment and work combination which would maximize the physiologic differences expected. Accordingly, each subject walked at 4.8 km/hr with each system (40 min walk, 20 min rest and 40 min walk) at 49°C, 20% R.H. (≈29°C T_{WB}). Three point Mean Weighted Skin Temperature (MWST), Rectal Temperature (T_{re}), Heart Rate (H.R.) and Sweat Production (P) and Evaporation (E) were measured. Test Results show that: (1) no underwear resulted in significantly cooler MWST mean weighted skin temperature at minutes 60, 80, and 100; (2) T_{re} Rectal temperature was slightly lower at a given time interval with no underwear; (3) there was a rise in heart rate during the work periods, but no differences among underwear systems; (4) sweat production showed no differences; and (5) the ratio of Evaporated/Produced Sweat (E/P) showed that no underwear allowed better evaporative cooling (P<.01) than any of the other ~~three~~ systems. Neither fish nor ladder-net underwear appear to offer any advantage over regular underwear; subjective comfort ratings support these conclusions.

ratings support these conclusions from the physiologic data.

1. INTRODUCTION

Assessment of the insulation (clo) value and evaporative impedance (i_m/clo) value of a clothing system can provide an accurate estimate of the relative advantages of one garment or fabric over another with respect to the thermal protection associated with wearing the clothing. The techniques used are a valuable tool in clothing design, and such evaluations are desirable in studies of the man-clothing-job-environment-system for ordinary clothing as well as for such advanced concepts as clothing systems with intrinsic environmental conditioning sources. There are, however, effects of cut, drape, design and fit that must receive special consideration. Thus, care must be taken if air permeabilities differ widely or if a clothing design allows unusual air exchange during subject motion.

A multidisciplinary approach has been evolved in the Military Ergonomics Division at the US Army Research Institute of Environmental Medicine (USARIEM), Natick, MA to assess the thermal interactions between the environment, the uniform worn, the man, and his military task. The laboratory studies are conducted at three different levels of analysis, with each level providing information that can be related to the others, as follows: 1) the physical heat transfer characteristics of the uniform materials are measured by use of a classic heated-flat-plate and also a unique "sweating" flat plate; 2) complete clothing ensembles, with and without such additional items as gloves, headgear, or back packs, are

evaluated on a "sweating" copper manikin for the heat transfer characteristics of the clothing ensemble; the values obtained are used in biophysical calculations in a programmed computer model to predict the wearer's tolerance limits; 3) carefully controlled physiological trials are carried out in climatic chambers, with volunteer subjects dressed in these clothing systems, to validate or refine the computer-predicted tolerance limits (5).

2. METHODS

For the copper man evaluation, data was collected on our heated, sweating copper manikin for clothing designed to be worn in the hot-dry environment of the desert. The results clearly indicated that any underwear worn under the clothing decreased evaporative transfer, primarily as a result of the increased insulation thickness. When the copper manikin wore no underwear, the insulation value was a 0.2 clo lower than when any of three underwear systems was worn: a) a standard boxer shorts and t-shirt; b) a fish net "Brynje" or c) a ladder net "Brynje"; these three systems showed identical insulation measurements on the copper man (Table 1). However, these static measurements did not, and in fact can not, discriminate among clothing systems designed to be ventilated to different extents by wearer motion. This is an essential characteristic of the difference claimed for the fish net or ladder net "Brynje" type underwear, but in the static copper man measurements, no opportunity for movement of the still air layer next to the skin exists. Therefore a physiological trial was

designed to assess the subject generated air movement in a dynamic state, i.e. "the pumping action" produced while walking on a treadmill.

INSERT TABLE 1 ABOUT HERE

Eight average size, young, male, US Army volunteers served as subjects for the physiological, chamber study. All wore a desert uniform over: a) no underwear; b) standard boxer shorts and t-shirt; c) a fish net "Brynje" system; d) a ladder net "Brynje" system. The chimney effect provided by the ladder net "Brynje" has been stated to allow a greater, natural convection compared to the fish net "Brynje" underwear.

The desert uniform (Basic Uniform, Desert Hot Weather Clothing (Dry)) consists of a coat and trousers fabricated of a 220gm/m^2 cotton 70/30 nylon fabric. The underwear systems consisted of: 1) standard cotton boxer shorts and standard cotton, ½ sleeve, crew neck t-shirt; 2) fish net design[1], open-weave, ankle length bottoms with fish net design ½ sleeve, crew neck t-shirt fabricated of 50/50 polyester/ cotton material; 3) the ladder net design[1] system was the same configuration and 50/50 material as the fish net designed system.

Our USARIEM computer model for predicting rectal temperature and heart rate, as a function of activity, clothing and ambient temperature (2,4), was programmed with various combinations of temperature and activity levels to suggest the tolerance limits of our subjects wearing these

1. The fish net underwear was manufactured by Duofold, Inc. under the trade name "Norse-Net"; the ladder net underwear was manufactured by Scandinavian Knitters.

systems. The work regimen and temperature conditions for the physiological chamber study were chosen to discriminate as much as possible between these underwear systems, based on the results predicted using the measured copper man values for the clothing ensembles and varying such other input parameters as temperature, humidity, work rate and work-rest cycle.

Accordingly, the subjects wearing the desert uniform and, in random order each day, a different one of the underwear systems, walked in a Climatic Chamber at 49°C, 20% R.H. (or ~ 29°C wet bulb) on a motor-driven treadmill at 4.8 km/hr for 40 minutes,(Fig. 1) rested 20 minutes (Fig. 2) and then walked for another 40 minutes.

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INSERT FIGURE 1 ABOUT HERE.

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INSERT FIGURE 2 ABOUT HERE.

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The study was conducted over a 5 day period late in the spring, when the outdoor temperatures were warm but subjects had little natural heat acclimation. The first of the five days was used for familiarization and to induce significant heat acclimatization. The data being reported was also analyzed for day effect and none was found; i.e. the additional changes in acclimatization after the first day of the study did not confound our results.

Heart rates were measured by radial artery palpation before, during and after each work-rest period (minutes 0, 20, 40, 60, 80, 100). Rectal

temperatures (T_{re}) and three (3) point mean weighted skin temperatures (MWST) were measured continuously, and graphed, "on-line" outside the Climatic Chamber, using a Hewlett-Packard 9810 Programmable Calculator and plotter. Nude and clothed weights were measured before and after each chamber exposure. Sweat production was determined by nude weight changes, adjusted for water intake, while sweat evaporation was determined by the changes in clothed weight, similarly adjusted. The ratio of sweat evaporated to sweat produced was then determined. Subjects also evaluated the underwear systems subjectively with a questionnaire.

3. RESULTS AND DICUSSION

The mean value of the eight subjects' three (3) point mean weighted skin temperatures (MWST) and rectal temperatures (T_{re}) are presented in Figure 3. The lower portion of this graph clearly shows that

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INSERT FIGURE 3 ABOUT HERE

"no underwear" resulted in lower skin temperatures throughout the experiment; the difference was significant at minutes 60, 80, and 100. The value at minute 40 showed a significant difference between no underwear and standard underwear, but the ladder and fish net underwear just fall short of reaching required critical difference using Tukey's W technique. Thus, there is a rather obvious difference favoring no underwear but the three underwear systems did not show any significant differences from one

another.

The upper portion of Figure 3 presents the rectal temperature data. At all times, the men with no underwear were cooler than men with any of the underwear systems. There were significant differences between the "Brynje" systems and no underwear, at all time intervals, and with the standard underwear at all but minute 60. The differences between no underwear and the others were small (averaging 0.2-0.3^{o}C) but consistent at all times (P<0.05). It appears that, if the subjects had worked in the heat longer, the differences for both T_{re} and MWST would have become even greater. (No slope analysis was done).

Figure 4 shows the heart rates as measured from the radial pulse.

INSERT FIGURE 4 ABOUT HERE

The heart rate response during work, as opposed to at rest, is quite apparent in this data. The differences in heart rate between men wearing the various underwear systems are <u>not</u> statistically significant except at minute 60 when, at the end of the 20 minute rest in the heat, men with none or with fish net underwear have lower heart rates than with the other systems, and at the 100th minute, when heart rate is lower ($p \leq .05$) for the no underwear compared with ladder net. However, the general statement can be made that there were no consistent differences in the heart rates associated with the various underwear systems.

Sweat production, as indicated by nude weight changes adjusted for water intake, is shown in the upper portion of Figure 5. The greatest

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INSERT FIGURE 5 ABOUT HERE

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amount of sweat was produced with the two "Brynje" systems and least sweat with the no underwear condition. However, these differences were not significant.

The lower portion of Figure 5 shows the ratio of the sweat evaporated to the sweat produced. Several statistical methods of analysis all gave the same result; the no underwear condition allowed significantly better evaporation of the sweat that was produced. Again, the closeness of the three underwear systems suggests that there was very little, if any, pumping of air to facilitate evaporative cooling ($P<0.01$). It appears that either: a) there was no additional cooling by movement of the trapped still air layer of these systems; or b) there was not sufficient "pumping" at these work rates to enhance cooling.

The subjects were asked to subjectively evaluate the underwear systems. The findings agreed with the data shown; the no underwear system was preferred, followed by the standard underwear; the two net systems were the least preferred.

In extreme heat, man becomes almost totally dependent on evaporation of sweat for the cooling required to eliminate his heat production, at rest or at work. In the absence of blowing sand, biting insects, and risk of abrasion by movement through brush, and so on, doing without any clothing whatever affords the greatest thermal comfort in the heat, provided that there is no solar heat load to be rejected and that ambient air temperature

is not greatly above skin temperature (5).

Belding (1), discussing clothing as a factor in heat elimination during work in hot environments in 1942 stated,; "Small, but measureable increases in coolness may be obtained by omitting the undershirt, opening the neck of the shirt, and rolling sleeves and pant legs". These, and our, conclusions would apply equally to a cold environment, where the no underwear condition would be cooler than any of the other 3 systems, but the other 3 would be essentially identical. Darling (3), investigating the physiological effects of two types of "Brynje" Vests in the cold in 1944, found "no measureable effect of the Norwegian type of "Brynje" vest on either the rate of sweating or the total amount of moisture uptake of the clothing during marching". Thus, there seems little reason to pursue further the concept of mesh or net underwear for thermal comfort in either hot or cold environments. Whether they may, or may not offer improvements in tactile sensation is a different, unanswered question.

In conclusion if evaporative cooling is the objective, it seems apparent that any underclothing within a clothing system inhibits evaporative transfer. In addition, the advantage in thermal comfort claimed for fish and/or ladder net underwear over conventional underwear does not appear.

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TABLE I

Copper Man Evaluation of Underwear for Desert Uniform

Clothing Systems	Clo	i_m	i_m/Clo
Desert Uniform with No Underwear	1.46	.40	.27
Desert Uniform with Shorts and T-Shirt Underwear	1.64	.38	.23
Desert Uniform with Fish Net "Brynje" Underwear	1.65	.39	.24
Desert Uniform with Ladder Net "Brynje" Underwear	1.65	.37	.23

CAPTIONS FOR FIGURES

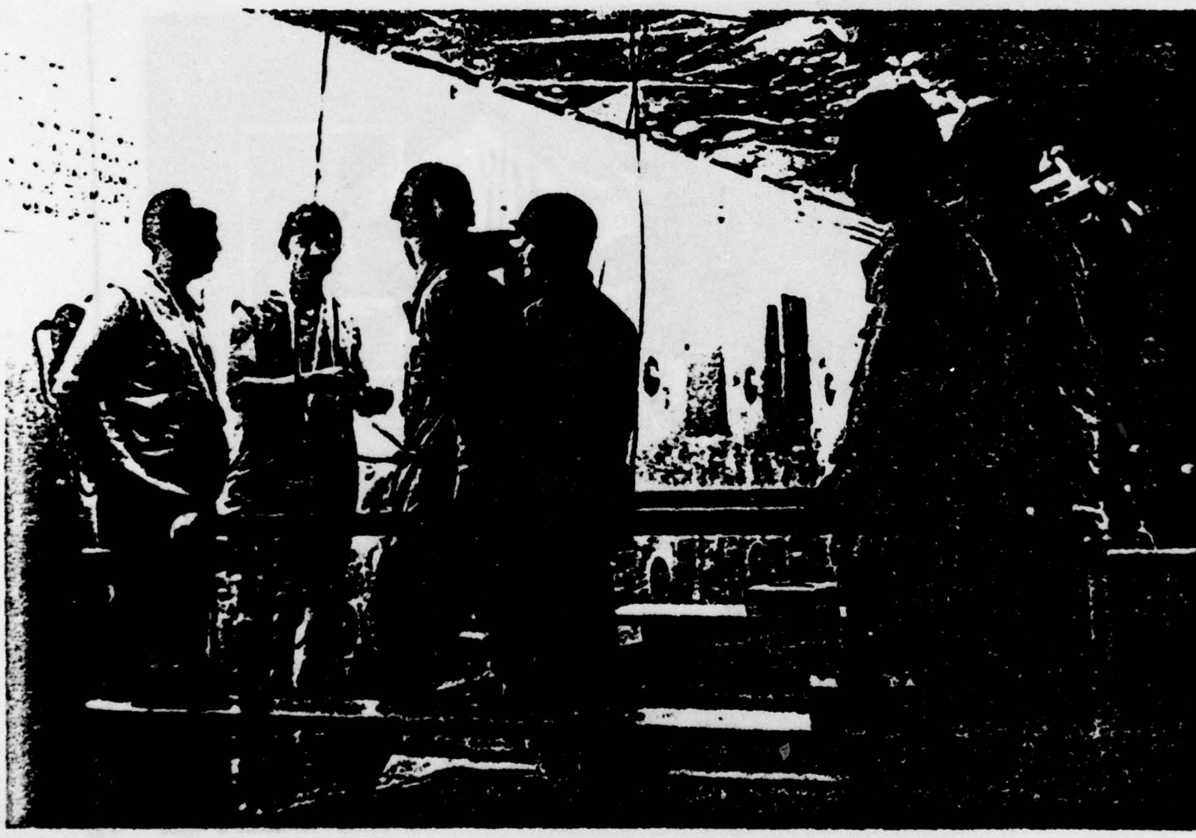
FIGURE 1 - Subjects Walking on Treadmill in Climatic Chamber

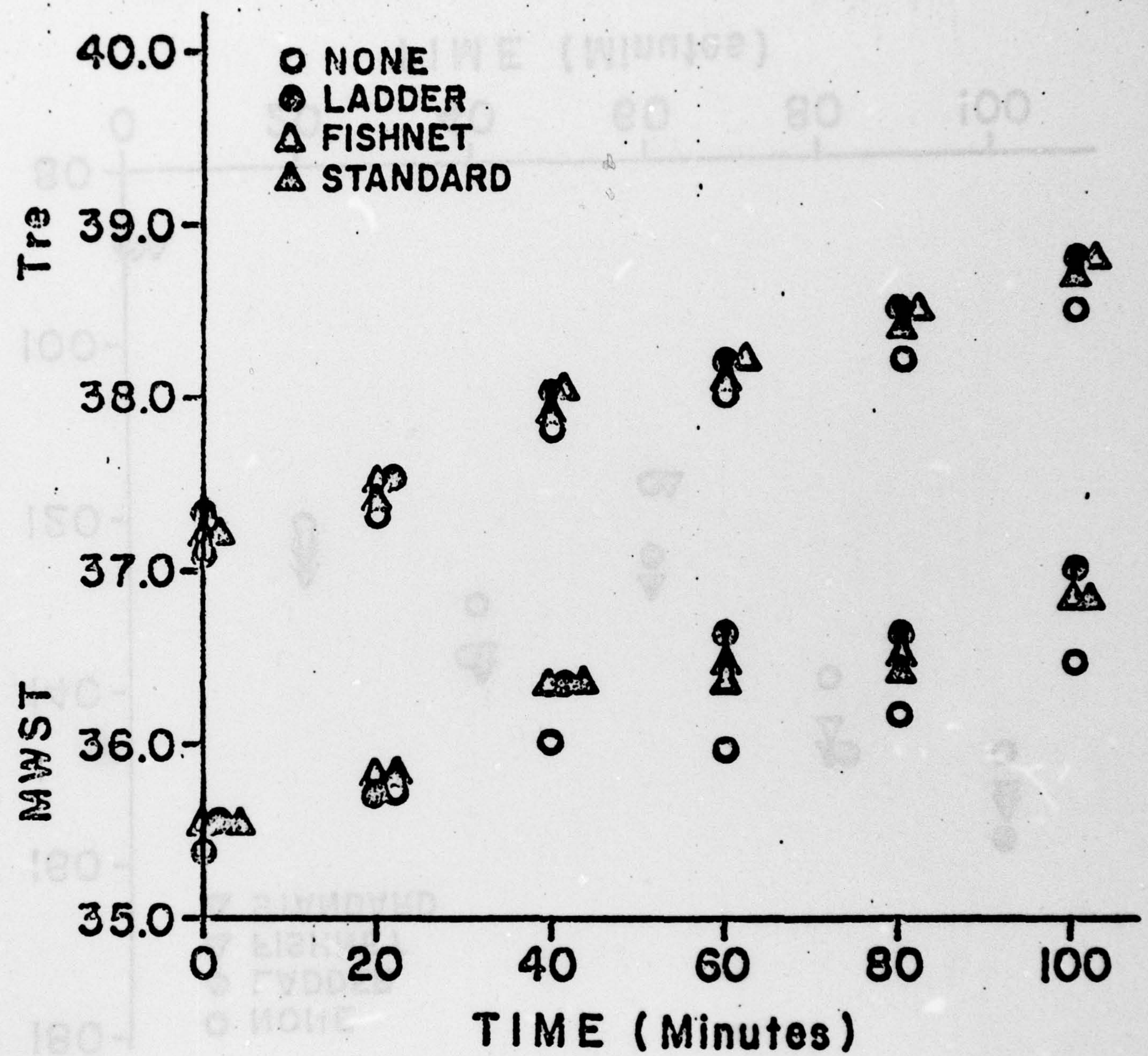
FIGURE 2 - Subjects Resting on Benches in Climatic Chamber

FIGURE 3 - Mean Weighted Skin Temperature (MWST) and Rectal Temperature (T_{re}) in ^{o}C for Various Underclothing Systems

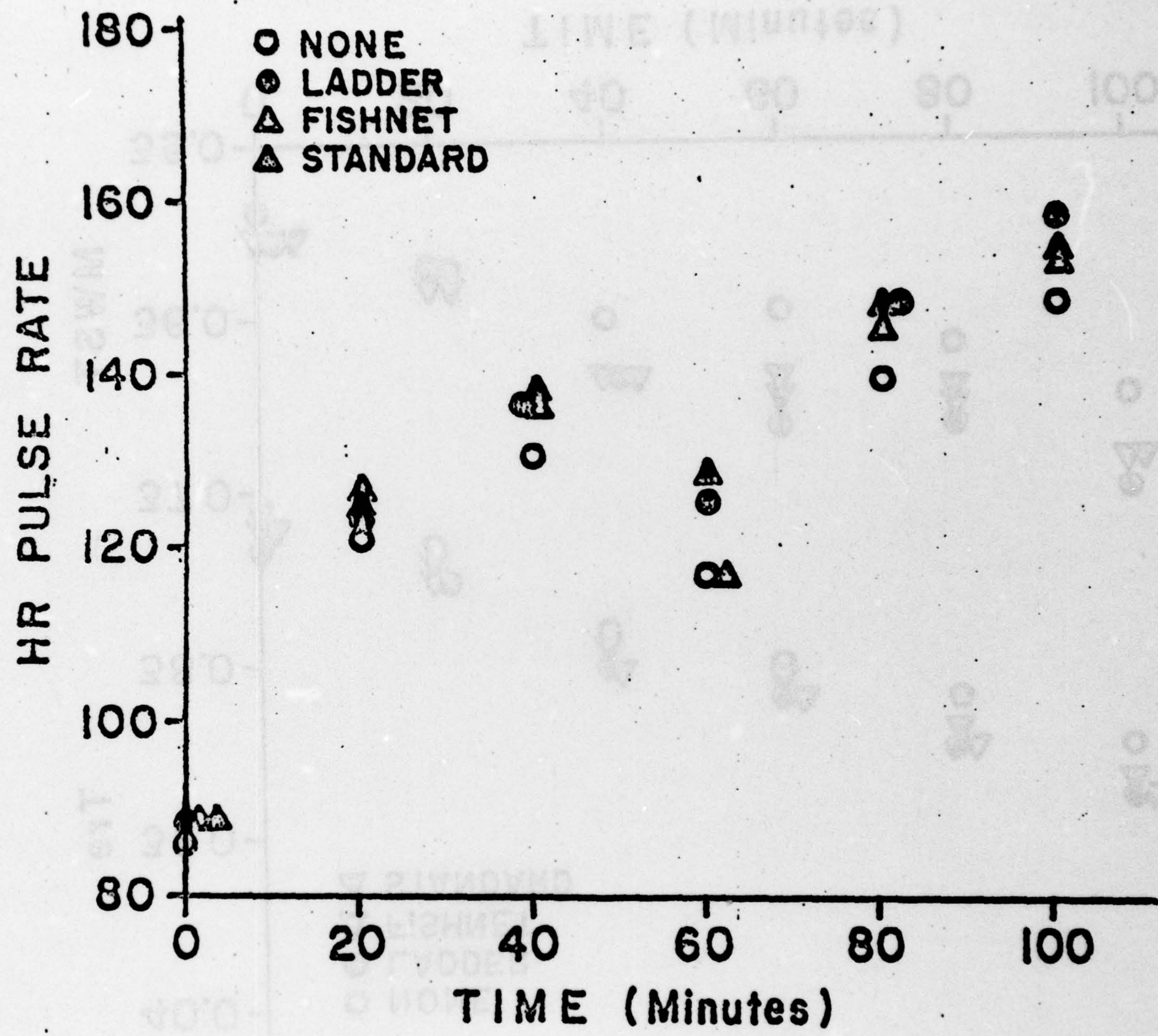
FIGURE 4 - Heart Rates (b/min) for Various Underclothing Systems

FIGURE 5 - Sweat Production and Ratio of Sweat Evaporated to Sweat Produced (E/P) for Various Underclothing Systems





NONE
LADDER
FISHNET
STANDARD
Tre
MWST
40.0
39.0
38.0
37.0
36.0
35.0
0
20
40
60
80
100
TIME (Minutes)


HR PULSE RATE
180
160
140
120
100
80
0
20
40
60
80
100
TIME (Minutes)
NONE
LADDER
FISHNET
STANDARD

Underwear System

None	Standard	Fishnet	Ladder Net	
1.734	1.740	1.836	1.838	$CD_{.05} = .149$

Sweat loss - nude weight change (kg)

None	Standard	Fishnet	Ladder Net	
.774	.703	.678	.670	$CD_{.05} = .059$

Evaporated sweat/sweat produced

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When underclothing of any type is worn, data collected using our static, copper manikin clearly indicate a slightly increased insulation and decreased evaporative transfer. In order to assess air movement in the dynamic state ("pumping"), the present study involved 8 man (21.2 yr., 175.2 cm and 69.1 kg) to evaluate four underclothing systems worn under a desert uniform: a) no underwear; b) std boxer shorts and t-shirt; c) fish net "Brynje"; and d) ladder net "Brynje". The physiological trial was designed using the copper man data to select an environ-

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